DEVELOPMENT AND OPTIMIZATION OF LIGHTWEIGHT CONCRETE USING SUSTAINABLE AGGREGATES AND ADDITIVES

A

SYNOPSIS

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This is to certify that the thesis titled **"DEVELOPMENT AND OPTIMIZATION OF LIGHTWEIGHT CONCRETE USING SUSTAINABLE AGGREGATES AND ADDITIVES"** is an original piece of work done by Ashish Kumar under my supervision for the degree of Doctor of Philosophy in Civil Engineering, in Abhilashi University Chail Chowk Mandi H.P. I also certify that this work has not been submitted to any other University for a Ph.D degree.

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DECLARATION

I hereby declare that the dissertation synopsis entitled **"DEVELOPMENT AND OPTIMIZATION OF LIGHTWEIGHT CONCRETE USING SUSTAINABLE AGGREGATES AND ADDITIVES"** to be submitted for the partial fulfillment of the Degree of Doctor of Philosophy in Civil Engineering is my original work and the dissertation has not formed the basis for the award of any degree, diploma, associateship or fellowship of similar other titles. It has not been submitted to any other University or Institution for the award of any degree or diploma.

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CHAPTER-1

INTRODUCTION

1.1 Introduction

The term lightweight concrete, also known as no-fines or low-fines concrete is being used these days, but as the development and the modern world advance, it becomes increasingly necessary to develop, transform and apply this in the field. The reason is quite simple, which lies in its name: lightweight, having weight less than normal concrete. The reason behind its light weight is the density that is packed into it. The appreciation for lightweight concrete is due to the intrinsic nature of lightweight aggregates and how they influence the properties of concrete made from them.

"Lightweight concrete" is the term which is preferred by the American Concrete Institute (ACI).This term is mostly used rather than the more scientifically correct term of lower density concrete (1)."Lightweight concrete" has mainly 3 basic ingredients lightweight coarse aggregates, normal weight fine aggregates and possibly some lightweight fine aggregates. Now there is another term which is quite similar to it i.e. "All lightweight concrete". All lightweight concrete is concrete made with mainly the fine and coarse aggregates all being light in weight. Lower density concrete can be made using lightweight aggregates that have within their mass an array of vesicules or air voids that render these aggregates of significantly lower density than normal weight aggregates concrete (density ~2400 kg/m^3). When these lower density aggregates are incorporated in a concrete mixture they can produce a structural grade concrete with a density of about 1850 kg/m^3. In addition to the very obvious reduction in mass, the other advantages that lightweight concrete can provide include increased thermal insulation, extended moist curing and increased durability.

A critical comparison of the rewards and liabilities related with the use of lightweight concrete were carried in many studies and it revealed that the lightweight concrete is a preferred material and it should not be construed as a negative inference for normal weight concrete. Reason being simple and straight i.e. lightweight concrete in some instances may have enhanced capabilities that fully justify its use. Lightweight aggregates made from natural deposits of volcanic materials such as pumice, sintered fly ash, and special deposits of silica-rich shale, clay and slate heated to about 1150°C are the main focus of some cases. Other low density aggregates such as

polystyrene beads and cold bonded fly ash are also there but they are not associated with reinforced concrete. The appreciation for lightweight concrete is due to nature of aggregates and their end product. These aggregates have within their mass an array of vesicules or air voids which can be seen in Fig. 1. The main capabilities and special properties are due to size, spacing and degree of interconnection of the voids. Reduction in the density of the concrete is well appreciated by the structural engineers and designer, since over half of the dead load in a structure is weight of the concrete. Of course an increase in vesicularization results in a significant decrease in particle strength, but this does not prevent the lightweight concrete from being used for high strength applications (2). Another key concept is that stiffness of the aggregate closely matches the stiffness of the matrix so stress concentrations are eliminated or at least greatly reduced to an extent. This low stress concentration in the lightweight system explains why a high strength concrete can be made from a relatively low strength particle. Now there is always a strength ceiling characteristic of each type of aggregate that means increased strength generally cannot be achieved unless higher cement contents in added to the mixture. The reduced stress concentration around lightweight aggregates substantially reduces micro cracking.

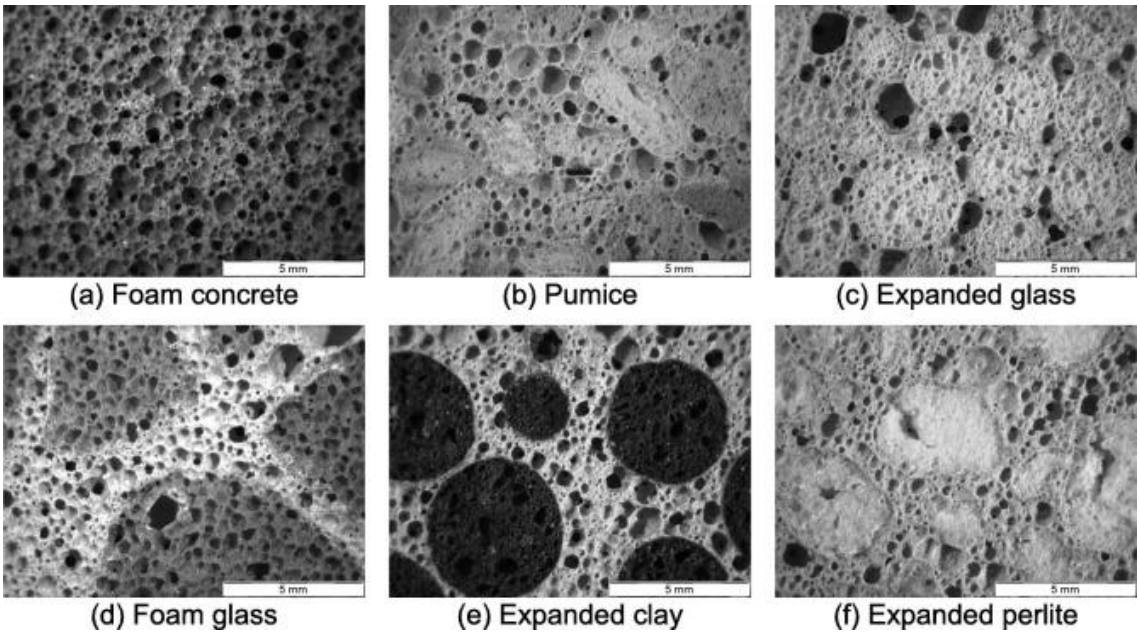

Fig.1.Microstructure of Light weight and Foam concrete

Less Micro cracking reduces the permeability of the concrete and enhances ability to protect embedded steel reinforcement from corrosion. It was found that when subjected to applied compressive stress, the onset of micro-cracking in lightweight concrete starts after around 80% of the ultimate compressive stress is reached, whereas in normal

weight concrete value is before 60% of ultimate compressive stress. These data indicates that service loads, thermal stresses and other volume changing influences have less effect on the permeability of lightweight concrete (3). Also, during the passage of the shale, clay or slate particles through the rotary kiln, they are heated to temperatures that activate their silica rich surfaces so that they act as pozzolans that can substantially improve the nature of the aggregate–cement paste interface.

1.2 Structural Applications/Case Studies

Lightweight aggregates can be used to make high strength concrete. Weight reduction achieved is one of the first major applications of lightweight concrete in high rise buildings. Since 1915 many buildings have been built with lightweight concrete using different materials for floor slabs such as sintered fly ash one example is Canary Wharf Building in London, UK. Another example with another material expanded slag aggregates for floor slabs and infilling walls is in Canada, the Toronto Dominion Center that has 56 floors and elevation of 230 m. Lightweight concrete is always in the list of material of choice where specialized or unique solutions are required and which can get converted to basic needs construction with time and requirement. Uses of pre-soaked expanded shale lightweight aggregate in 100-120 mm thick slabs have also been studied in some cases. Other advantages include pumping the concrete to high rise building easily. Lightweight concrete is durable and is enormously useful for repairing and refurbishing ageing infrastructure. Many bridges have been successfully constructed with this material and these factors are good for long-term performance.

"Lightweight-concrete" produces an economical solution in rehabilitating and upgrading existing bridges, especially where they involve an increase in the load rating or a widening of the roadway because on existing footings construction becomes easy. The positive weight to mass ratio gained through the use of lightweight concrete has resulted in new and novel construction techniques. Lightweight concrete has been used extensively for offshore oil platforms that are built at an onshore graving dock or in a fjord where deep water is close to shore. This was achieved by using equal proportions of lightweight and normal weight coarse aggregates on or close to land, towed in place and then bottom founded. The superior strength to weight ratio of lightweight concrete is well recognized, making it the preferred material for floating concrete structures. Heidrun Platform built in 1996 with a density of 1940 kg/m^3 and strength of 70 MPa, provide the assurance necessary to specify the use of this material

for marine applications. For example, floating LNG terminals built with lightweight concrete hulls incorporating offshore gas storage, facilities to liquefy the gas, and terminal facilities for re-gasification and storage before piping the gas to shore are in the foreseeable future.

1.3 Production of lightweight concrete

Normal-weight concrete is usually made from deposits of granular aggregates created by weathering or glacial actions later gets transport either naturally of through machinery, but lightweight aggregates such as expanded clay, shale and slate are manufactured in a controlled way from specifically selected large deposits of raw material that tend to be uniform in composition. This means the intrinsic variability within normal-weight concrete mixtures is greatly reduced in comparison to those made with lightweight aggregates. This uniformity enables producers of structural lightweight aggregates to provide detailed guidance on concrete mixture proportions to the purchasers of their aggregates.

Typical high strength concrete mixtures shows that high performance concrete can be achieved through the use of commercially available lightweight aggregates (4). Normally for most domestic and industrial construction much lower strengths are adequate. Mixture proportioning is greatly simplified; typical normal-weight concrete mixtures can be used as reference in preparing lightweight concrete mixtures by simply replacing normal-weight aggregate with lightweight aggregate on a volume basis. Most commercial lightweight concrete mixtures contain about 5% entrained air and have a slump that is reduced by the same ratio as the density of the final concrete mixture has been reduced. For e.g. a 2400 kg/m^3 normal-weight concrete mixture with a slump of 120 mm becomes 90 mm slump with a lightweight concrete with a density of 1800 kg/m^3, both of which have essentially equal workability and the same compressive strength at 28 days.

1.4 Future trends

The intrinsic advantages of using low density material for structural purposes is on rise factors such as low volatile release rate from construction materials and the desirability of using inherently non-combustible materials rather than fire retardant treated combustible materials puts lightweight concrete and concrete masonry in a very good

position for future growth. For this reason the industry should and may prosper in the foreseeable future in spite of the projected reduced rate of growth of the cement industry in the developed world.

In India and other Asian nations as well as in much of the developing world, there are clear signs of an awakening to environmental problems and in particular to global warming and the associated problem of the rise of ocean levels. In its more populated areas India is not well endowed with good aggregate sources but has fly ash from power generating stations, burning of stubble in India's Northern region which is a ready source of material to make lightweight aggregates. Extensive research is being carried out at various centers, including at the Indian Institute of Technology in Madras, to make a stronger and more highly expanded aggregate than is available using current manufacturing procedures. A particular advantage of lightweight aggregates derived from fly ash is that worldwide immense supplies of coal are available at low cost, burning of stubble in India's North region mainly and all over India is easily available. In India, as well as in most other places where coal is burned, the ash produced is in excess of the need for it as a supplementary cementing material. This surplus ash in an urban environment causes a disposal problem unless it is processed into lightweight aggregates which should find a ready market for its consumption.

Most nations have limited energy resources. By taking the molten slag directly from the iron blast furnace to a pelletizing machine, lightweight aggregates are produced with essentially a negligible input of energy. Industries in Canada and Russia have perfected this process and have been doing this for the past several decades. To have a viable industry producing lightweight aggregates there needs to be a base load market to sustain the industry through the vicissitudes of the structural market. The building industry is noted for its boom and bust behaviour, a factor causing many well-managed firms to come to grief. In the past two decades many markets have been developed and old ones have been reinvigorated to produce an important base load for the industry.

Need:-

Aging workforces and back problems caused by lifting the heavy normal-weight units will easily appreciate mass to weight ratio in any form i.e. in concrete form or lighter masonry block mixture, Horticulturalist can prefer lightweight aggregate to absorb and slowly released water and liquid nutrients that may reduce labour costs as well as minimize weight which can be used in many forms, modern method of developing green

roofs over high rise structures can be of importance in construction industries, load balancing needed on low bearing capacity soils for highway fills, dump yards or parking lots etc., vehicle arrest pads of loose lightweight aggregates are used at the ends of runways and at run off ramps at the bottom of steep hills in mountainous regions, water treatment facilities use vesicular crushed aggregates to provide more exposed surface area for vegetative growth, lightweight aggregates are used in asphalt mixtures to produce high friction surfaces, developing skid-free surfaces in winter from lightweight aggregates which can be saturated with salt water can be used because delayed release of the salt from the vesicular aggregates provides either ice removal or helps key the aggregates into the ice surface.

In conclusion, the successful development of all of these new markets is vitally important if we want to have a healthy industry producing a suitable grade of lightweight aggregate for the structural market. At present, only a few of these markets are being effectively promoted by any given producer. To accomplish this, all of the above uses need to be promoted on a worldwide basis or good models of this type are needed to be carried out. The other method for market development in that material is outright success and has a good word of mouth from consumer. The closely focused conferences on structural lightweight concrete held in the recent past generally did not serve this purpose. Other similar or correlated produced related to lightweight aggregates are foamed concrete, recycled concrete, fiber reinforced foamed concrete etc. Inspiration of mix and mashing of some of ingredients from these products can also be done to obtain a better light weight aggregate concrete.

CHAPTER-2

LITERATURE REVIEW

2.1 Information:

Light weight concrete a.k.a. lower density concrete is wide term it incorporate or coincide with many other types of concretes such as fibrous concrete reinforcement, lightweight concrete, recycled materials in concrete, foamed concrete, polymer concrete etc. as sustainable aggregates may have many form depending upon geography, morphology and according to other different conditions. The material produced mainly should have density of about 1850 kg/m^3.

Lightweight concrete have been made from natural volcanic materials later early builders learned that expanded aggregates were better suited for marine facilities than the locally available beach sand and gravel and it leads to thought that materials can vary according to region and needs.

The literature review of the lightweight concrete prepared from low density aggregates can be divided into the following categories:

- Overview of traditional and lightweight concrete, including their properties and applications.
- Review of various lightweight aggregates (e.g., expanded clay, shale, perlite, pumice, vermiculite).
- Discussion on sustainable and recycled materials for lightweight concrete (e.g., fly ash, slag, recycled plastic).
- Previous studies on the mechanical, thermal, and acoustic properties of lightweight concrete.
- Identification of gaps in current research.

2.2 Literature review:

(Sassine et al., 2021)[5] studied the thermal performance of lightweight concrete applications in building envelopes. This paper evaluates the thermal impact of lightweight concrete (LWC) in building constructions. By pouring an 8 cm thickness of LWC on the roof and slab, and replacing traditional hollow concrete blocks, the thermal properties of two samples were determined. Numerical simulations were conducted on a

traditional detached house, revealing that LWC can reduce heating and cooling needs by up to 9% and 13% respectively.

(Agrawal et al., 2021)[6] studied the performance of Structural Lightweight Aggregate Concrete for Sustainable Construction. Due to its ability to withstand earthquakes, lightweight aggregate concrete, or LWAC, is becoming a more popular and sustainable building material for high-rise buildings by utilizing trash and industrial by products. This research examines how LWAC affects the characteristics of concrete and show how that it can be applied to structural. Conclusion shows LWAC can guarantee environmental sustainability by lowering waste and promoting sustainable growth in the building industry.

(Mahmmod et al., 2024)[7] studied the characteristics of Lightweight Concrete Fabricated with different types of Strengthened Lightweight Aggregates. This study mainly explores the use of crushed autoclaved aerated concrete (CAAC) and crushed clay brick (CCB) as lightweight aggregates. The study also examines the impact of LWA porosity on LWC properties. End Results shows that both CCB and CAAC can be used as full substitutions for normal-weight coarse aggregate because they improve properties and strengthen the porous structures with enhanced mechanical performance.

(Wongkvanklom et al., 2018)[8] investigates the structural Lightweight Concrete Containing recycled Lightweight Concrete Aggregate .Concrete can be enhanced by using recycled lightweight aggregate (RLA) as a replacement for fine limestone aggregate. The mixture of silica fume and a super plasticizer enhances the strength of SLC. The result shows that SLC has satisfactory 28-day compressive strengths of 16.5-30.5 MPa and density of 1600-1800 kg/m3. However as the RLA content increases, compressive strength, modulus of elasticity, and thermal conductivity decrease, while water absorption and porosity increase.

(Khoshvatan & Pouraminia, 2021)[9] studied the effects of additives to lightweight aggregate on mechanical properties of structural lightweight aggregate concrete. The study investigated the impact of additives like perlite, LECA, and pumice on the mechanical properties of structural lightweight aggregate concrete with a results showing that lightweight concrete made from a mixture of these materials could be 25-30% lighter than conventional concrete. Other key finding of study is that amount of cement directly affects the strength of the concrete, with increased cement compressive strength

also increase the compression ratios for 7 to 28 days for lightweight concrete were between 0.67-0.8, indicating a good indirect tensile strength for structural lightweight concretes.

(Bejan et al., 2020)[10] examined the light weight concrete with wastes. This study is about the wastes and new materials and their effect factors in construction industry, the new materials being Eco concrete, Geo-polymer concretes etc and new materials induced in them are fly ash, silica fume, tire waste, agro waste etc..This waste either replaces aggregates or cement in traditional concrete .Light weight concretes are main focus in this context.

(Ramezani et al., 2024)[11] researched the structural lightweight concrete containing basalt stone powder. The study explores the use of basalt stone powder in Structural Lightweight Concrete (SLWC) by incorporating Light Expanded Clay Aggregates (LECAs) and basalt stone powder. Compressive strength and density of the SLWC were determined which revealed an optimal strength of 42 MPa and a density of 1715 kg/m3 and the high porosity of LECA contributing to low durability. External coatings of emulsion and fiberglass were applied to enhance the durability consisting three layers of emulsion bitumen and fiberglass which improved the concrete's durability by over 90%.

(Pramusanto et al., 2020)[12] studied the high strength lightweight concrete with expandable perlite as the aggregate. In this study lightweight concretes were made with the composition of expandable perlite combined with natural sand having volume of 50% and concrete with 100% expandable perlite as the aggregates. The volume of the aggregates was varied from 80% up to 89%,the concretes were measured for their density and tested for the mechanical and absorption properties. Results show that expandable perlite has effect in reducing the concrete density and the strength also decrease as the expanded perlite aggregate increase.

(He et al., 2020) [13] studied the dynamic mechanical properties for recycled aggregate concrete under Tensile-Compressive States. This study investigated the tensile failure of recycled aggregate concrete (RAC) under biaxial tensile-compressive stress test with a result showing that RAC's dynamic mechanical behaviour was affected by strain rates, stress ratios, and RCA substitution percentages. As the strain rates increased, RAC's strength improved, but its compressive strength decreased to a certain limit. This study

also establishes a new tensile-compressive failure criterion under complex stress states, considering the effect of loading rates.

(Liu et al., 2011)[14] studied the water absorption, permeability, and resistance to chloride-ion penetration of lightweight aggregate concrete. It mainly examines the impact of cumulative lightweight aggregate (LWA) content on concrete's water absorption, permeability, and resistance to chloride-ion penetration via results, showing that LWAC resistance to chloride penetration decreases with increase in LWA content. One other major found of study is that LWAC with the coarse LWA had similar water sorptivity, permeability, and resistance to chloride-ion penetration compared to NWAC and both NWAC and LWAC had lower sorptivity and higher resistance to chloride-ion penetration compared to cement paste.

(Al-Khaiat & Haque, 1999)[15] studied the strength and durability of lightweight and normal weight concrete. This study shows that a research project has been undertaken in Kuwait University to investigate the long-term strength development, durability of lightweight aggregate concretes (LWAC's) and a normal weight concrete (NWC) under hot dry and hot humid coastal exposure conditions. This paper exactly reports the strength development and durability characteristics of specimens exposed to the seaside up to an age of 9 months. They find that the water penetrability of LWACs seems to be more sensitive to the extent of initial curing than it is for NWC. And also concludes that the depth of carbonation, sulphate, and chloride penetration were somewhat higher than that NWC50 under the similar exposure regimes.

(Schackow et al., 2014)[16] studied the mechanical and thermal properties of lightweight concretes with vermiculite and EPS using air-entraining agent. This study aimed to compare mechanical and thermal properties of lightweight aggregate concrete with two kinds of lightweight aggregates, vermiculite and Expanded Polystyrene (EPS) by using air-entraining agent and superplasticizer admixture. Researchers further states that for better reliability, a statistical analysis of the results compressive strength and density were used. And they showed that the addition of air-entraining agent left the lightweight concretes even lighter, but less resistant. Advantages of EPS lightweight concrete is that it has higher strength and is lighter than with vermiculite where as Vermiculite lightweight concrete had lower thermal conductivity than EPS.

(Amran et al., 2015)[17] studied review on properties and applications of foamed concrete. Foamed concrete possesses characteristics such as high strength-to-weight ratio and low density by using foamed concrete dead loads on the structure and foundation reduces, contributes to energy conservation, and lowers the labor cost during construction. This paper provides a review of foamed concrete constituents, fabrication techniques, and properties of foamed concrete. This literature review also aims to provide a comprehensive insight into possible applications of foamed concrete in the construction industry today.

(Ramamurthy et al., 2009)[18] presented a classification of studies on properties of foam concrete. Though foam concrete was initially envisaged as a void filling and insulation material, there have been renewed interest in its structural characteristics in view of its lighter weight, savings in material and potential for large scale utilization of wastes like fly ash. The focus of this paper is to classify literature on foam concrete in terms of constituent materials (foaming agent, cement and other fillers used), mix proportioning, production methods, fresh and hardened properties of foam concrete. Based on the review, the research needs have been identified are: (i) developing affordable foaming agent and foam generator, (ii) investigation on compatibility between foaming agent and chemical admixtures, use of lightweight coarse aggregate and reinforcement including fibers, (iii) durability studies, and (iv) factors influencing foam concrete production viz., mixing, transporting and pumping.

(Huang et al., 2015) [19] presented proportioning and characterization of Portland cement-based on ultra-lightweight foam concretes. Conclusion recommends that ultra-lightweight foam concretes can be used for energy efficiency in buildings due to their thermal insulation, fire resistance, and durability; however they are expensive and not universally available. This study investigated Portland cement-based ultra-lightweight foam concrete by finding that it can be prepared using Portland cement, fly ash, hydrogen peroxide, and chemical admixtures.

(Cong & Bing, 2015)[20] presented properties of a foamed concrete with soil as a filler material. In this research the basic ingredients for soil-based foamed concrete were soil, foaming agent, and ordinary Portland cement. The effects of silica fume and foam content on the physical characteristics of the concrete, including its water resistance, pore structure, dry density, and 28-day compressive strength, were mainly investigated

and according to the experiment's findings it was found that, the physical characteristics of soil-based foamed concrete are significantly influenced by the amounts of silica fume and foam.

(Namsone et al., 2017)[21] presented the durability properties of high performance foamed concrete. Foamed concrete (FC) in the modern building industry is famous due to its simple tech. and wide range of properties that it possess; however, it also faces issues like shrinkage and decreased strength compared to the aerated autoclaved concrete .In order to create durable high-performance FC, intensive mixing technology and modifying micro admixtures can be applied in future states the researchers as the characteristics of FC include strength, density, water absorption, carbonization, and frost resistance. So creating more durable FC will increases material life cycle and promote the rational use of natural resources.

(Chen, 2023)[22] presented experimental study on the application performance of foamed concrete by preparing on base on colloidal NanoSiO2-stabilized foam. This study investigates the stability of foaming agents and prefabricated foam by adding colloidal nanoSiO2 (CNS) at different dosages. The end result shows that CNS enhances the stability of foam, especially when the dosage is ≥ 1 % which leads to increased surface visco-elasticity modulus and surface shear viscosity in the foaming agent. Further the addition of CNS also improves the stability of foamed slurry and hardened foamed concrete however, the effect of CNS decreases after 14 days of hydration. This study up to some extend proposes mechanism for the stabilization effect of CNS on these materials.

(Dilli et al., 2015)[23] studied comparison of strength and elastic properties between lightweight structural and conventional concretes which were designed with aggregates of expanded clay. This study investigated the compressive strength, modulus of elasticity (MOE), Poisson's ratio, and ductility of lightweight aggregate concrete (LWAC) mixtures by comparing them to conventional concrete (CC) mixtures. Results show that a LWAC mixture varies between 20 MPa and 70 MPa depending on the unit weight of concrete and a LWAC mixtures show a reduction in MOE with more brittle behaviour compared to CC mixtures. A new model for predicting MOE was suggested by researchers.

(Bernhardt et al., 2014)[24] studied the effects of additives on the properties of lightweight aggregates which were produced from clay -lightweight aggregates, with additives like Na2CO3, SiO2, Fe2O3, and Fe. They were further examined for their properties, strength, density, and expansion behaviour. Addition of metallic iron powder increased porosity but reduced density.

(Lotfya et al., 2016)[25] studied durability properties of lightweight self-consolidating concrete developed with three types of aggregates. The durability properties of lightweight self-consolidating concrete (LWSCC) using furnace slag, expanded clay, and expanded shale were examined in study. LWSCCs show superior fire resistance, salt-scaling resistance, and enhanced resistance against sulphuric acid attack however, non-air entrained LWSCC mixtures struggled to withstand severe freezing and thawing cycles thus indicating the need for improved aggregate quality and properties in lightweight concrete.

(Vijayalakshmi et al., 2018)[26] presented a review on structural concrete using expanded clay aggregates. This paper discusses the use of Expansive Clay Aggregate (ECA) in producing structural lightweight concrete. It further discusses the aggregate's physical and chemical properties, as well as the influence of pelletization parameters on aggregate properties. The study finds that ECA has a specific gravity 16-46% lower than normal weight aggregates and has higher water absorption. In end the concrete's 28-day compressive strengths and durability make it a promising material for structural concrete development.

(Du, 2019)[27] examined the properties of ultra-lightweight cement composites with nano-silica particles in it. The effect of nano-silica on various properties of ULCC is studied and it was concluded that the use of nano-silica in ultra-lightweight cement composites (ULCC) enhances its strength, microstructures, and mechanical properties. New test by combining expanded glass particles and cenospheres as fine aggregates were done and it was found that the strength of the ULCC mix increases to 27 MPa which implies that the addition of colloidal nano-silica (CNS) significantly improves the strength, enhancing resistance against water and chloride penetration. This study also highlights the beneficial effects of nano-silica on transport properties.

(Yu et al., 2015)[28] the authors current work offers a design process for extremely light concrete that may have been used in monolithic concrete constructions as a thermal

insulator and as a load-bearing element. To ensure a tightly packed matrix made of a binder and light aggregates made from recycled glass, a particle grading model is utilized. With an approximate dry density of 650–700 kg/m3, the created ultra-lightweight concrete exhibits good thermal and moderate mechanical capabilities at 28-days the compressive strength stands at around 10–12 N/mm^2.

(Liu et al., 2015)[29] presents a model to estimate the durability performance of both normal and light-weight concrete. This study evaluates the impact of water accessible porosity and oven-dry unit weight on concrete's resistance to chloride-ion penetration. The empirical models established here correlates total charge passed and chloride migration coefficient with concrete properties. This is validated by independent experimental results from two different concrete mixtures; this model provides a good estimate of concrete's durability performance.

(Mo et al., 2016)[30] presented a review on bond properties of lightweight concrete. Lightweight concrete (LWC) is gaining interest due to its design flexibility and cost-effectiveness. However, lack of information on bond properties could hinder its application in the construction industry. This study review explored the bond performance of LWC, including lightweight aggregate, foamed, and no-fines concrete and mentions their compliance with bond requirements, enhancing its feasibility for structural applications.

(González-Corrochano et al., 2009)[31] study characterized lightweight aggregates made from fly ash and washing aggregate sludge from thermal power plant. The resulting aggregates met UNE-EN-13055-1 standards and showed the lowest loose bulk density, lowest dry particle density, lowest water absorption, and highest compressive strength. These lightweight aggregates could be used in insulation, geotechnical applications, horticulture, gardening, and prefabricated structures.

(Terzić et al., 2015)[32] studied and analyzed the impact of pelletized fly ash-based aggregates and their behaviour of lightweight concretes. Four lightweight artificial aggregates were produced, based on mechanically activated or non-activated low-calcium fly ash and water glass. Further the lightweight concrete's behaviour was compared to normal-weight concrete and the optimal production combination was determined using methodology of response surface. The other key findings support the

principle of waste material reusing that enable us to a cleaner and economically sustainable concrete manufacturing process.

(Lotfy et al., 2015)[33] presented modelling and optimization of self-consolidating lightweight Concretes with expanded shale aggregates. The impact of significant mix design parameters on the characteristics of lightweight self-consolidating concrete containing expanded shale (ESH) aggregates has been investigated through statistical models described in this research. This model applies to mixtures with different binder contents and water-to-binder ratios.

(Ibrahim et al., 2020)[34] presented durability of structural lightweight concrete containing expanded perlite aggregate. This research paper presents statistical models that do the analysis impact of key mix design parameters on basis of the properties of lightweight self-consolidating concrete (LWSCC) with expanded shale (ESH) aggregates. The models developed are valid for mixes with varying water-to-binder ratios and binder content. Mainly three industrial class ESH-LWSCC mixtures are developed and their validation on their performance base is done.

(Parmo et al., 2018)[35] presented the mechanical properties of lightweight concrete made with Pumice. Pumice a light-coloured rock formed from volcanic eruptions is used in manufacturing lightweight aggregates concrete in this study. Pumice silicate (SP-2) from Gresik is substituted as coarse aggregates resulting in a lightweight aggregate of volume of about 717 kg/m^3. The compressive strength obtained from the specimen cylinder was tested at days 7, 14, and 28 had values of 15.23, 13.86, and 13.88 Mpa respectively were obtained. It was concluded that Pumice is suitable for lightweight structural concrete manufacturing.

(Przychodzień & Katzer, 2021)[36] emphasised focuses on the characteristics of lightweight aggregate concrete made from vermiculite and sintered ash. The purpose of the study is to evaluate the viability of using sintered fly ash as a substitute aggregate by analyzing the effects on the mechanical, physical, and durability characteristics of material. After testing it was found that the combination of exfoliated vermiculite aggregate and sintered fly ash the concretes prepared had compressive and tensile strengths ranging from 20.3 to 54.2 MPa.

(Xu et al., 2015)[37] cement-based composites were prepared by using Paraffin or expanded vermiculite. This study developed a new paraffin/expanded vermiculite composite for cement-based composites named LW-TESCCs. The optimum paraffin was calcined at 800ºC for 1h. It was found that composite PCM had good thermal stability and resistance further it can reduce indoor air temperature with energy saving. The composite was fabricated using a vacuum impregnation method.

(Hanif et al., 2016)[38] studied mechanical as well as thermal insulating properties of green lightweight cement composite having aerogels and fly ash. Cement composite was created with superior qualities having a light weight. Fibers were also added made of polyvinyl alcohol. The composite materials material prepared showed decreased thermal conductivity and increased specific strength and amount of aerogel affected the weight directly.

2.3 Gaps in the Study

Despite significant advances in lightweight concrete technologies, several gaps in the existing literature and practical applications remain. Identifying these gaps is crucial for guiding future research and innovations. Here are some of the primary gaps in the study of lightweight concrete materials:

1. Limited Understanding of Long-Term Performance

- **Durability and Longevity:** There is insufficient long-term data on the durability and performance of lightweight concrete under various environmental conditions, such as freeze-thaw cycles, chemical attacks, and prolonged load-bearing.
- **Aging and Degradation:** The mechanisms of aging and degradation in lightweight concrete, especially those using novel or recycled aggregates, are not well understood.

2. Optimization of Mix Designs

- **Proportioning and Compatibility:** More research is needed to optimize the mix proportions of lightweight concrete to achieve a balance between strength, workability, and density. The compatibility of different lightweight aggregates

with supplementary cementitious materials and chemical admixtures needs further exploration.

- **Standardization:** Lack of standardized mix design procedures for different types of lightweight aggregates makes it challenging to ensure consistent quality and performance.

3. Sustainable and Recycled Materials

- **Recycled Aggregates:** There is a need for more comprehensive studies on the use of recycled aggregates, such as crushed concrete, glass, and plastic, in lightweight concrete. The effects of these materials on the mechanical and durability properties of concrete are not fully understood.
- **Environmental Impact:** Detailed life cycle assessments (LCA) of lightweight concrete made with various sustainable and recycled materials are limited. There is a need to quantify the environmental benefits and potential trade-offs of using these materials.

4. Thermal and Acoustic Properties

- **Thermal Insulation:** While the thermal properties of lightweight concrete are often mentioned, there is limited quantitative data on how different types of lightweight aggregates and mix designs affect thermal conductivity and overall energy performance.
- **Acoustic Performance:** The sound absorption and transmission properties of lightweight concrete are not well documented. More research is needed to understand how lightweight aggregates influence acoustic performance.

5. Structural Applications

- **Load-Bearing Capacity:** The structural applications of lightweight concrete, particularly in high-rise buildings and critical infrastructure, require more research. There is a need to validate the load-bearing capacity and seismic performance of lightweight concrete in real-world scenarios.

- **Fire Resistance:** The fire resistance properties of lightweight concrete, especially when incorporating novel aggregates and additives, are not thoroughly investigated.

6. Economic Analysis

- **Cost-Effectiveness:** Comprehensive cost-benefit analyses comparing lightweight concrete with traditional concrete are limited. More studies are needed to evaluate the economic viability of lightweight concrete, considering factors such as initial costs, maintenance, and lifecycle costs.
- **Market Acceptance:** There is a gap in understanding the barriers to market acceptance and widespread adoption of lightweight concrete. Factors such as availability of materials, construction practices, and industry standards need further exploration.

CHAPTER-3

RESEARCH OBJECTIVES

This research focuses on the development and optimization of lightweight concrete using various sustainable aggregates and additives. The study aims to evaluate the mechanical, thermal, and acoustic properties of the developed lightweight concrete and compare its performance with traditional concrete and provide materials or study with confidence and reliability by using the information and guidelines available or by developing a new set of steps for designing of lightweight concrete so construction practices and structures can be designed based on light weight aggregate concrete performance with sustainability. The main objectives in study are:-

1. To identify and evaluate different types of lightweight aggregates for concrete production.
2. To develop mix designs incorporating crushed brick aggregates and Alccofine.
3. To assess the mechanical properties, durability properties, thermal insulation and acoustic performance of lightweight concrete.
4. To analyze the environmental and economic benefits of using lightweight concrete in construction.
5. To develop an analytical model/correlation for prediction of strength and durability properties of lightweight concrete using various sustainable aggregates and additives.

CHAPTER-4

RESEARCH METHODOLOGY

Methodology:

Selection of Lightweight Aggregates: Aggregates selection will be done according to type or size of aggregate. The steps involved are:-

- Evaluating the properties of various lightweight aggregates (e.g., density, absorption, particle size).
- Selection of aggregates based on availability, sustainability, and performance criteria as per the requirement of study.

Mix Design Development: Similar to other concrete preparation casting, moulding, de-moulding and curing are some of main operations which may be involved. Curing may be done according to temperature. The other points included with these main steps are:-

- Formulation of concrete mix designs by incorporating selected lightweight aggregates using supplementary cementitious materials (e.g., fly ash, slag ,silica fume) and chemical additives (e.g., super-plasticizers) to enhance the performance.
- Optimizing the mix proportions to achieve desired properties such as density, strength, and workability.

Experimental Testing: It involves the checks and stages of testing the specimen which have been prepared with different materials and their mixture after it is being moulded or is to be mould into desired shape and size. Testing involves:-

- Mechanical Properties: Assessing compressive strength (effect of density on compressive strength, effect of W/B ratio on compressive strength, effect of coarse aggregate on compressive strength, effect of fiber type and volume fraction on compressive strength), tensile strength, flexural strength, and modulus of elasticity etc. for knowing the mechanical properties.
- Thermal Insulation: Measuring thermal conductivity and evaluating thermal insulation performances are mainly the main operations in study of thermal insulation.

- Acoustic Performance: It is related to gain and loss of energy forms or related properties i.e. test sound absorption and transmission loss properties.
- Durability: Evaluating resistance to freeze-thaw cycles, sulphate attacks, and chloride penetration are mainly involved.

Environmental and Economic Analysis:

- Perform a cost-benefit (CBA) analysis comparing lightweight concrete with traditional concrete. It mainly includes material, production, transportation, installation, operational costs etc with identification of benefits such as environment, resource conservation etc. With help of a tabular form and real world market data of specific region.
- A life cycle assessment (LCA) to evaluate the environmental impact of lightweight concrete production can also be carried with software depending upon the level and skill of technology with budget issues.

CHAPTER-5

EXPECTED RESULTS AND DISCUSSION

Expected Outcomes:

- Identification of effective lightweight aggregates and optimal mix designs for lightweight concrete.
- Quantitative data on the mechanical, thermal, and acoustic properties of lightweight concrete.
- Insights into the environmental and economic benefits of using lightweight concrete in construction.

Potential Applications and discussion:

- Use in high-rise buildings to reduce structural load and foundation requirements.
- Application in thermal insulation systems for improved energy efficiency.
- Utilization in acoustic insulation for noise reduction in residential and commercial buildings.
- Development of lightweight precast concrete elements for faster and more efficient construction.
- For absorbing and slowly releasing water and liquid nutrients that may reduce labour cost.
- Modern method of developing green roofs over high rise structures.
- Load balancing on low bearing capacity soils for highway fills parking; dump yards lots etc. or for load-bearing capacity and seismic performance in structures.
- Developing skid-free surfaces in winter from lightweight aggregates which can be saturated with salt water.
- Sustainable and recycled light weight material produced by incorporating recycled aggregates.

CHAPTER-6

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